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LONG-TERM TRADEOFFS FOR SUSTAINABILITY POLICIES
IN THE AREA OF ENVIRONMENTAL TOXICOLOGY

AN ECONOMIC ANALYSIS OF A NIMBY SYNDROME

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Abstract

The paper aims at providing an overview of economic evaluation problems regarding toxic materials, with special emphasis on persistent micro-pollutants. These issues will be analyzed from the viewpoint of ecological sustainability.

After some introductory remarks the paper will spell out in more detail the externalities involved in hazardous materials production (in terms of health impacts, locational externalities and other social costs). It will be argued that such external impacts are in contrast with an ecologically sustainable development, as reflected inter alia in the care for human health or for future generations (in terms of inter-temporal social costs, deprivation of meaningful development options, etc), the carrying capacity of the environment (in terms of reducing the user potential of the biosphere), and so forth.

Various attempts in economics to assess in more precise (mainly monetary-economic) units the damage costs incurred by the environment will be reviewed concisely. Some attention will also be given to the potential of a social rate of discount for incorporating the interest of future generations. Given the high risks involved for future generations, a plea will be made to develop sustainable policy strategies based on quality standards. In order to stimulate a proper and legal disposal system for hazardous materials, a bonus system will be proposed. A multi-temporal optimal control model for such a deposit-refund system will be developed as an analytical framework for policy analysis. The paper will be concluded with various items for a research agenda in the economics of a NIMBY syndrome.



1. Prologue

Since the beginning of the 1970's already, many attempts have been made to devise environmental policies that were focussing the attention on long-term strategic issues (general environmental degradation, extinction of rare species etc). The future was mainly pictured by means of simulation models whose empirical validity however was not deeply rooted in observed facts. As a consequence, a wave of criticism emerged which in the past decade has almost led to a disappearance of such long-term environmental management models. In recent years however, the awareness has grown that - despite considerable progress in coping with the impacts of 'ordinary' pollutants such as carbon-monoxide, sulfur-dioxide, nitrogen oxides - the remaining category of pollutants (toxic materials, non-degradable waste) may be much more dangerous to human health and to the survival of many species or even entire ecosystems.

Since the publication of the Brundtland Report (see WCED 1987) a global concern has arisen on ecologically sustainable economic development. The crucial question here is whether economic progress (including technological transformation processes) is compatible with the ability of future generations to meet their own needs (in terms of both economic and environmental goods). There is sufficient empirical evidence which demonstrates clearly that a unilineal evolution of current trends will create disastrous outcomes for the next generations, so that we are facing a difficult choice situation in which the advantages and disadvantages of alternative development scenarios have to be traded off on the basis of both economic and environmental criteria, while taking into consideration the interest of future generations.

From an economist's viewpoint there would be no reason to be concerned about the interest of future generations, if the rate of environmental degradation would not be higher than the rate of technological progress in coping with environmental degradation. Indeed some economists claim that the future could be left to the next generations, as it is plausible that the next generations have even more options to deal with environmental issues than the current one (cf. Baumol 1968).

However, the empirical justification of this assumption is very weak and there is by no means a plausible reasoning that this strategy would ensure a sustainable development.

There is, however, one more problem. Various hazardous waste materials do not only have an ad hoc effect on the environment, but may have a long-term non-reversible effect, so that in that case future

generations will be deprived from feasible desirable environmental options. Especially, toxic materials and biologically non-degradable pollutants may jeopardise the potential of next generations. Persistent micropollutants (PMP's) are a good example of long-term environmental degradation that may not only reduce the range of options for the future, but may also reduce the quality of life and even health of future generations. In this context, it is worthwhile to make a reference to Solow (1986), who - notwithstanding his modest concern on future generations - claims that they should have access to a certain standard of living or level of consumption.

An important question here is thus whether we have to allow for a flexible development path where - temporally or structurally - environmental quality conditions might fall below a critical level or whether a strict system of environmental sustainability conditions would have to be imposed (e.g. by claiming that the level of future environmental capital may not fall below the current level) (see for instance, Ciriacy-Wantrup 1952 and Pearce 1988). The latter choice option would of course require a very strict and global environmental policy in the short run, as will be shown later on.

There is another point which deserves some attention. To some extent the environment provides complementary inputs with respect to conventional inputs in the economic process. For instance, without a high quality environment agriculture is unable to generate an economically efficient and acceptable product quality (see Nijkamp and Soeteman 1988). Thus the environment is part of the production function of the economy (see also Opschoor 1987 and Siebert 1982). It has to be well maintained - just like any other capital stock - and of course to be taken into account in planning strategies as a valuable scarce resource as well. Thus the environment does not only have the character of a consumption good (for short and long term need satisfaction), but also of an - often exhaustible - production factor (serving the efficiency needs of current and future generations in a productive sense).

It is, however, difficult - if not impossible - to identify an optimal level of environmental capital that would guarantee the highest sustainability. In James et al (1989) five factors are mentioned which have to be taken into account:

- ethical notions such as the level of solidarity owed to future generations;
- the present and future degree of (riskless) substitution between the various elements of the environmental capital stock;

- the present and future degree of (riskless) substitution between elements of environmental capital, man-made capital and human capital;
- the degree of robustness of the biosphere in accommodating different spatial distributions of economic activities and the associated environmental impacts;
- the future institutional capacities for managing or adapting to environmental changes.

Clearly, the evaluation of the future against the present along two dimensions (economic progress and ecological sustainability) is far from easy. Besides, whether it would be acceptable to impose the condition that for PMP's the future level should not exceed the current level is a question which deserves more scientific research. In order to answer this question four stages would have to be considered:

- environmental monitoring (inventory of hazardous materials in the external environment);
- biological monitoring (identification of causal chain mechanisms in living organisms);
- biological effect monitoring (assessment of impacts on living organisms);
- health monitoring (evaluation of impacts on health).

A good example of these stages can be found in the Netherlands in the area of soil pollution. At the moment all areas earmarked for new residential purposes have to be carefully investigated regarding the presence of toxic material; in this process the first stage is compulsory. If the soil concerned is polluted with hazardous waste materials, the next three steps will have to be followed. No permission for building dwellings will be granted, unless a 'clean statement' has been issued, sometimes after an extensive cleaning programme (in approx. 25 percent of all cases in the Netherlands). The costs are extremely high, but in view of the risks involved (in terms of health costs to current and future generations), the decision has been taken to go for a 'risk-free' strategy. Such a strategy does make sense if there is some evidence of future impacts on health conditions or on the quality of ecosystems. In the next section, more attention will be paid to external costs of hazardous materials in general and PMP's in particular.

2. External Costs of PMP's

External costs of PMP's - and in general of hazardous materials and toxic waste - may be subdivided into **actual** costs and **potential** costs. Actual costs refer to those sacrifices which have an immediate negative impact on the welfare position of an individual or the group under consideration (including their health, their need for a well kept ecosystem etc). A usual phenomenon here is that everybody wants to enjoy the fruits of our welfare society, but that in general the social costs involved are not fully accounted for and hence transferred to others. This NIMBY (not-in-my-back-yard) phenomenon is particularly relevant in the case of locational issues (e.g., dumping of waste material, siting of a nuclear power plant etc). Thus it seems as though our economies are - at the level of individual decision making - trying to maximize individual benefits while at the same time the transfer of externalities to others is also maximized. This leads no doubt to sharp conflicts among different groups or places. Clearly, in various cases the transfer of externalities is not done purposely. For instance, according to Winteringham (1985, p.5) "of the growing range and weights of agrochemicals (fertilizers, pesticides, etc) only small fractions of pesticides reach the target pests, and in the case of fertilizers nitrogen especially, usually little more than half is usefully recovered in the crop. Inevitably, proportions of the agrochemical 'residues' find their way out of the target area and they can impair environmental quality or harm non-target wildlife populations. These side-effects, which include the selection of entire field populations of pesticides-resistant pests, can reach unacceptable levels in tropical and temperate agricultural areas".

Potential costs are latent costs which may emerge elsewhere (notably in the future), but so far they have not yet materialized as actual costs. Clearly, if such costs will be effectuated, they will affect the welfare level of the group concerned (i.e., the welfare of future generations). The problem is, however, that future generations cannot defend their rights and they do not have formal lawyers in an environmental court. Thus as a consequence their welfare level is co-determined by the benevolence of the present generation. Thus the NIMBY phenomenon which is already very strong in current periods is even much stronger when it comes to future generations. As a consequence, the existence of many toxic dumps, PCB's in heating and air-conditioning systems, and potential pollution from herbicides and pesticides point to an built-in tendency toward jeopardizing the interest of the future (cf. Chatterji 1987). The following table may serve as an illustration.

WASTE GENERATION BY WASTE TYPE IN NEW YORK

<u>Waste Type</u>	<u>Percent of Total Small Quantity Generator Waste Stream Accounted by Each Waste Type</u>	<u>Estimated Amount of Waste Generated in New York State by Waste Type</u>
1. Arsenic Wastes	*	*
2. Cyanide Wastes	*	*
3. Dry Cleaning Filtration Residues	2	1,170
4. Empty Pesticide Containers	1	585
5. Heavy Metal Dust	*	*
6. Heavy Metal Solutions	*	*
7. Heavy Metal Waste Materials	*	*
8. Ignitable Paint Wastes	1	585
9. Ignitable Wastes	1	585
10. Ink Sludges Containing Chromium or Lead	*	*
11. Mercury Wastes	*	*
12. Other Reactive Wastes	*	*
13. Paint Waste Containing Heavy Metals	*	*
14. Motor Freight Terminals Waste	1	585
15. Photographic Wastes	3	1,755
16. Solvent Still Bottoms	*	*
17. Spent Plating Wastes	1	585
18. Spent Solvents	18	10,520
19. Solutions or Sludges Containing Silver	1	585
20. Strong Acids or Alkalies	5	2,925
21. Used Lead-Acid Batteries	62	36,240
22. Waste Formaldehyde	1	585
23. Waste Inks Containing Flammable Solvents or Heavy Metals	*	*
24. Waste Pesticides	*	*
25. Wastewater Containing Wood Preservatives	*	*
26. Wastes containing Ammonia	*	*
	100**	58,000**

* This category represents less than one percent of total.

** The sum of the columns does not equal the total shown because the small categories of less than one percent are not shown.

PMP's may - through their cumulative effects and persistent nature - involve serious health and ecological risks. However, little is known about health effects (e.g., anemia, cancer, liver disease etc) and even less is known about long-term ecological effects (e.g., the impacts of the exponentially growing number of resistant pests). The potential costs mainly charged to future generations, however, have never been seriously estimated.

Even the actual costs of hazardous waste (including PMP's) in terms of health effects are extremely difficult to assess, but may plausibly be assumed to be higher than expected. For instance, Williams (1987) refers to a recent article in the New York Times: "A recent, unreleased APA report, quoted in the New York Times in 1985 (October 3, page 1) said, '...at least, 7,000 accidents involving toxic chemicals have occurred in the United States in the last five years, killing 135 and injuring nearly 1,500'.....' with over 200,000 people requiring evacuation'." In many cases, two general types of actions against hazardous waste are possible, viz. restricted use and restricted siting.

In various cases, new sources of pollution (e.g., plants) have to install the best available treatment technology in order to meet strict environmental quality standards, although under certain conditions in the US the 'bubble principle' allows for an exchange between higher emissions of new sources and (at least) an equivalent reduction of existing sources. However, in case of persistent, accumulative and dangerous materials such as PMP's, a substitution between different pollutants in favour of a higher PMP emission does not seem to be an acceptable strategy in view of the potential long-term health effects. In that case, restrictions on emissions (e.g., by means of stringent control technologies) are the only way out. Changes in siting of the sources of such persistent pollutants make only sense from the viewpoint of a NIMBY attitude, but disregard the cumulative and un-anticipated future effects of PMP's.

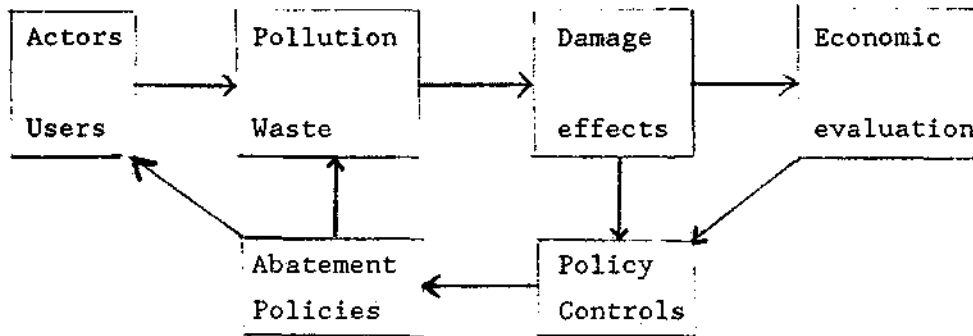
In view of the great many dangerous effects of toxic and hazardous waste, a variety of policy responses have emerged in the US, such as: implementation of stringent federal environmental standards to control all toxics releases to the environment, comprehensive and enforceable occupational health and safety programmes, and heavy financial penalties for regulatory violations.

However, to make policies more acceptable and hence more effective, more information would be needed on the economic implications of PMP's.

In the next section, a concise critical overview of various economic evaluation methods in this field will be given.

3. The Economic Toolbox

Any attempt at evaluating in economic terms the consequences of dangerous materials should make a distinction between physical dose-effect relationships, economic evaluation, and influences of policy controls. This is briefly sketched below.



3.1 Dose-effect relationships

Dose-effect relationships picture causal chains of effects from a source upon the ultimate target. Given the persistent and long-term nature of PMP's and the complexity of such causal chains the final impacts of PMP's are usually difficult to assess. Such effects may be manifold. They may relate to both ecosystems such as reductions in the number of species, change in habitat, change in behaviour or in reproduction rate, sensitivity to diseases, increase in mortality rates (see Bunyan and Stanley, 1983) and human health (such as carcinogenic effects, allergic reactions, or neuro-toxic effects; see Strigini, 1982). For PMP's especially the chronic toxic effects are extremely important, but precise impact assessments are for the time being very rare (see Ware, 1980).

3.2 Economic evaluation

There are various, sometimes competitive, ways of evaluating the damage effects of environmental pollution. Examples of such evaluation methods are:

- functional evaluation; this method refers to all (elimination and compensation) costs that are necessary to take account of the loss of environmental functions incurred by polluting activities; despite the

theoretical elegance of this method, it is lacking operationality in a practical policy context.

- energetic evaluation; this method aims at assessing environmental damage costs by assessing the embodied energy in all transformation processes involved; this energy flow method is essentially a limited approach, as it takes for granted the existence of a single basic production factor (i.e., energy) while neglecting influences from the demand side.
- evaluation of financial and amenity losses; this method attempts to estimate financial losses (i.e., the monetary value of changes in the demand for marketable goods and services as a result of environmental damage) and the amenity losses (i.e., the remaining (social or psychological) damage which is not directly embodied in financial losses); techniques for assessing the financial losses are amongst others:
 - ☐ social cost-benefit analysis
 - ☐ cost-effectiveness analysis
 - ☐ community impact analysis
 - ☐ shadow project analysis;
 techniques for assessing the amenity losses are inter alia:
 - ☐ surrogate markets (e.g., based on hedonic prices)
 - ☐ alternative (avoidance) costs
 - ☐ survey techniques
 - ☐ multicriteria analysis

Thus there is a wide variety of different techniques available, and in various cases they have proven to be successful. However, in case of long-lasting effects of non-degradable pollutants hardly any operational evaluation method has been designed and used in practice.

The potential (or latent) costs of PMP's are indeed extremely difficult to gauge. The assessment of actual costs is also difficult, but in this framework more attempts have been undertaken (see Eitjes and De Haan 1987). Here one may make a subdivision into economic damage to (1) human beings, (2) plant and animal species, and (3) water, air and soil.

(1) Human beings.

Financial losses refer here mainly to three categories, medical costs, loss in income and productivity, and psychic costs. Amenity losses may be assessed among others by means of human capital methods, implied valuation methods, or risk reduction methods (cf. Sussman 1984). An example of an assessment of costs of pesticide

use on human health can be found in Pimentel (1980) and is presented here for the sake of illustration.

Human Poisining Costs	Total costs
1. Cost of hospitalized poisinings	
2,831 hospitalized poisinings x 3.7	
days in hospital x \$127.70/day	
hospital fee	\$ 1,337,619
2,831 hospitalized poisinings x 3.7	
days in hospital x \$16.04/day doctor	
fee.....	168,014
1,000 workers hospitalized poisinings	
x 6.67 days lost work x \$34/day.....	226,780
2. Cost of non-hospitalized poisinings	
30,000 physician treated x 1.5 physician	
visits x \$20/visit.....	900,000
40% Non-hospitalized physician treated	
x 42,200 physician treated x 6.67 days	
lost work x \$34/day.....	3,828,046
3. Cost of emergency room treated	
poisinings	
12,200 Emergency Room poisinings x	
\$25/visit.....	305,000
4. Cost of fatalities	
52 Accidental Fatalities x \$1 million..	52,000,000
5. Cost of human cancer due to pesticides	
0.5% cancer x \$25,000 million.....	125,000,000
Total.....	\$183,765,459

(2) Plant and animal species

There is a variety of methods for assessing the costs of environmental damage with regard to the flora and fauna, for instance, survey techniques, recreation evaluation methods, productivity assessment of agricultural land etc, although actual figures may incorporate many biases (see also Pimentel 1980).

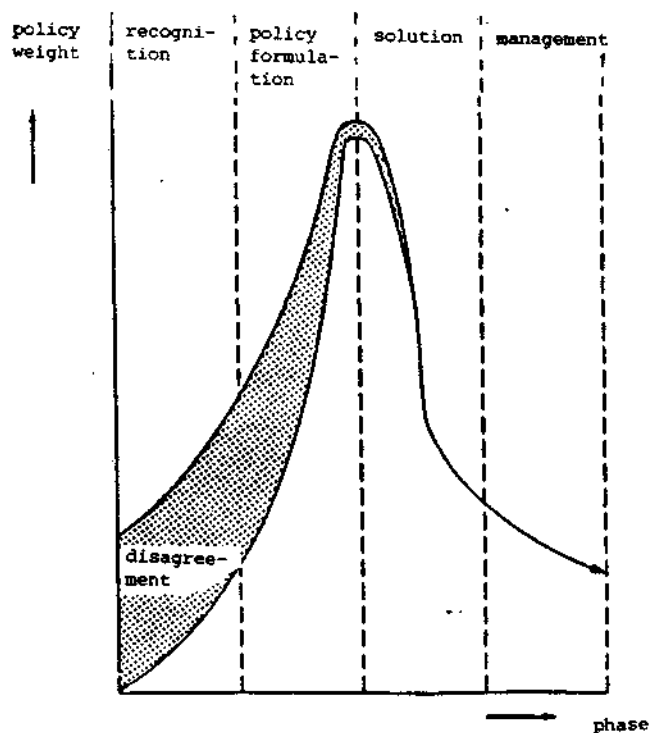
(3) Water, air and soil.

These categories are transmitters of pollutants and may lead to a diversity of environmental damage costs. Accumulated obnoxious materials, synergetic effects and long-range effects make it especially difficult to assess in monetary terms the economic consequences of PMP's. Although it is known that such polluting materials may affect the productive functions, the regulating functions, and the carrier and information functions of the natural environment, little information is as yet available on changes in these functions.

In conclusion, besides dose-effect uncertainties, economics itself has not yet developed a reliable and acceptable toolbox for judging PMP's. Especially the complex causality relationships of non-degradable PMP's make it extremely difficult to arrive at politically meaningful references.

3.3 Policy control

Policy controls serve to reduce the friction between the real (or predicted) state of environmental systems and the desirable (or socially acceptable) state of the environment. However, before such a state will be reached, one encounters usually a policy life cycle with four phases: awareness, policy formulation, solution, management. This is reflected in the figure below adapted from Winsemius (1986).



evidence suggests that significant external benefits from the conservation of natural capital stocks may be expected. In case of a lower social rate of discount, one may expect more maintenance of large stocks of natural resources and more available options for present and future consumers.

Thus it is sometimes argued that in case of long-term projects the government - as a 'trustee of unborn generations' - should use a social rate of discount that is lower than the discount rate reflecting the (individual) opportunity cost of postponing the consumption of goods or services. This is especially emphasized in case of multi-generational evaluation problems, as the usual social rate of discount is co-determined by time preferences of individuals who are neither necessarily concerned with future interests of themselves nor of society as a whole (cf. also the so-called 'isolation paradox'; see Sen, 1967).

In the past decade the problem of multiple generations has been quite extensively discussed in view of the exhaustibility of natural resources. The argument for a downward adjustment of the social rate of discount is based on the assumption that individuals have a myopic view on the future and hence tend to underestimate the impacts of current decisions upon long-term welfare related to the use of a finite stock of resources (cf. Herfindahl and Kneese, 1974, Krutilla and Eckstein, 1958, Marglin, 1963, Mishan, 1977, Myers, 1977, Page, 1977 and Pearce, 1977). Despite many variations in arguments, it is generally accepted that the interest of future generations may lead to a downward adjustment of the social rate of discount.

In a recent article by Nijkamp and Rouwendal (1988) the idea of flexible social rates of discount was generalized, by assuming a series of overlapping future generations each having its own specific social rate of discount (given the generation who presently has to decide on long-term strategic issues). It could be shown that under certain fairly general conditions future welfare implications could be fully accounted for in present decision-making.

(2) Imposition of Ecological Stock Constraints

Preservation of ecological stocks has been advocated as a way of ensuring sustainable development (see Goodland and Ledec, 1987 and Pearce, 1988). This would require a very stringent policy control

The shaded area in this figure indicates that in initial phases there is a great deal of uncertainty, conflict or tension on directions where to go and policies to adopt. Clearly, the more reliable the dose-effect and economic assessment the lower this uncertainty. In any case, based on results from scientific analysis, policies are developed as feedback mechanisms in order to provide stimuli to an enhancement of environmental quality.

The policy controls may be of a varied nature, such as prohibitions, financial penalties, subsidies, R&D investments etc. Of course, they depend on the foreseeable or known impact of the pollutant at hand. However, a time horizon covering multiple generations is usually regarded too long as a basis for immediate policy responses. Now the question has to be raised whether a re-orientation of our economic thinking might be helpful in generating the proper responses from the side of both policymakers and polluters.

4. Policy Responses to PMP Threats

In view of the aim of an ecologically sustainable economic development, various policy responses can be envisaged to cope with the dangers of PMP's. In a more general setting, it was recently argued by James et al (1989) that the following alternative guidelines for ecological preservation might be considered:

(1) Lowering the social rate of discount

By lowering the social rate of discount in economic analyses of long-term policy programmes or projects with a clear environmental implication, the future will automatically be regarded as more important than in conventional plan or project evaluation (see Gijssbers and Nijkamp 1988 and Nijkamp and Rouwendal 1988). The size of renewable resources left to future consumers will vary inversely with the social rate of discount. If the discount rate applied is relatively high, the stock of renewable resources will be exploited at higher rates, leading to a lower stock size (or to extinction at the end of the planning period) depending on alternative uses of the resource at hand and the discount rate used. Consequently, the economic welfare of future consumers may be adversely affected. Unfortunately, the benefits of natural resource stock preservation tend often to be underestimated. Even though the external costs of resource use are sometimes difficult to measure, most ecological

on exploitation rates and pollution emission. It is however difficult to define exactly the meaning of an ecological stock, as human activities will always lead to changes (positive and negative) in such stocks. Besides, each environmental capital has a potential for self-regeneration or rehalibitation, which also has to be taken into consideration. Nevertheless, in case of PMP's this idea would make sense, if this notion were interpreted as the aim to avoid any further increase of the stock of PMP's in the environment. This idea will be further discussed in section 5.

- (3) Environmental indicators, critical zones and safe minimum standards
By using a monitoring system based on environmental indicators, a timely recognition of critical zones in environmental quality may take place. Similarly, one may introduce safe minimum standards in order to ensure some quality control on environmental developments (see also for a game-theoretic exposition Bishop 1978). Clearly, it is not always possible to provide a solid basis for the imposition of safe minimum standards, as indicators are not always unambiguous (cf. Walters 1986). A major question is also whether such standards are necessarily very rigid, whilst ecosystems may go through various 'natural' evolutionary stages. Nevertheless, in case of dangerous toxic materials (including PMP's) a 'safety first' principle is likely a plausible strategy, as will also be further outlined in section 5.

(4) Environmental protection measures

Such measures take for granted that 'prevention is cheaper than cure'. From a long-term economic viewpoint, it is plausible to undertake such actions up to the point where the foreseeable marginal protection benefits are equal to marginal protection costs (see Hufschmidt et al. 1983). Clearly, in case of irreversible environmental effects stringent protection measures are a necessity. Such measures may of course pertain to both prohibitions (or standards) and financial incentives.

In conclusion, various policy directions can be followed. As long as large deficiencies in knowledge and predictive capabilities prevail, and if social goals other than economic efficiency are to be attained, a conservative approach to sustainable development and natural resource management is recommended. Economic efficiency analysis can be applied

within the constraints imposed by multiple objectives. Future options can be kept open by preserving natural capital stocks. In principle this can be achieved by use of the policy and management guidelines described above. In the next section an attempt will be made to develop a more rigorous analytical framework for these observations.

5. A Policy Model for PMP's

In the present section we will make a distinction between two types of PMP's, viz. those which have an immediate negative impact on the ecosystem or on human health and those which have a long-lasting effect with latent costs involved. In the first case (e.g. toxic materials) a stringent system of prohibitions is necessary in order to prevent further harm to the environment or health. In the second case, there is a scope for a more flexible policy, in which market incentives may be used to stimulate a reduction of waste disposal. The main problem inherent in strict prohibitions is the maintenance of policy regulations and laws. In various cases illegal practices (e.g., illegal dumping, transport to the Third World etc) may occur, which from a long-term perspective leads to uncontrolled waste dumping. Therefore, an alternative policy strategy for PMP's, based on sound market principles, may be envisaged (see also Kahn 1987). This will be clarified by means of a simple model.

The basic idea is that the stock of PMP's in the environment should not exceed a critical acceptance level; this threshold level may be related to either the safe minimum standard or the stock of environmental capital discussed above. If the current level of the PMP stock is below this level, there is for the time being no urgent problem. However, if the current level is above the threshold level, a policy strategy has to be adopted in order to reduce the current level towards the acceptable level by using market incentives. As mentioned above, prohibitions might lead to uncontrolled or illegal practice. The same holds true for a system of changes, as is shown by clear evidence from many countries. Thus essentially the simple 'polluter pays' principle tends to fail in the case of PMP's which are often only produced in small quantities and hence are easier to dispose. Of course, an alternative may be a 'pollutee pays' strategy, but this leads usually to strong reactions because of the underlying pollution rights principle. In our analysis we will propose a compromise version of a standards system, a 'polluter pays' system and a 'pollutee pays' system. Let us denote the stock of dangerous PMP's in the environment by z , measured in terms of

mass. Changes in this stock are the result of two forces: a decline caused by natural degradation of PMP's and a rise caused by the emission of new pollutants to the environment. Then we have in case of an uncontrolled disposal of PMP's:

$$z_{t+1} = z_t (1-\delta) + w_t \quad (5.1)$$

where δ is the rate of degradation (or 'depreciation') of the PMP stock and w_t the emission of new PMP's into the environment during year t . We will assume here that the critical limit for PMP's is equal to $\bar{z}$. Let us now assume a regulatory policy for waste disposal, so that w_t^* is the amount of PMP's properly disposed (i.e. it does not harm the environment). Thus the addition to the stock of PMP's is then $v_t = w_t - w_t^*$, so that (5.1) becomes:

$$z_{t+1} = z_t (1-\delta) + v_t \quad (5.2)$$

We also assume fixed emission coefficients for the generation of PMP's, so that we have:

$$w_t = \alpha q_t \quad (5.3)$$

where q_t is the mass of total production.

Following Kahn (1987) one may now use a 'deposit-refund' system (analogous to the beverage deposit-refund system), which means that, for each unit of PMP treated and deposited in a proper way, the producers will receive a unit bonus (or deposit-refund) the size of s_t units. However, in order to avoid unlimited production of PMP's and to stimulate a reduction of PMP's in production processes, a meaningful way of calculating the bonus is to relate the deposit-refund negatively to the emission coefficient (i.e., $1/\alpha$) and positively to the share of PMP's properly treated. In other words, the total bonus B_t would be:

$$B_t = (1/\alpha) (w_t^*/w_t) s_t \quad (5.4)$$

$$= \frac{w_t^* s_t}{\alpha w_t}$$

It is easily seen that in this case a higher bonus will only be gained, if the emission coefficient is reduced, the total amount of

waste is reduced or the total amount of properly treated waste is increased. Of course, the higher the value of s_t the higher the probability that w_t^* will equal w_t .

The determination of the level of s_t is surrounded with some uncertainty. Assuming now that the costs of the deposit-refund system will not be charged to an anonymous agency, but have to be financed out of charges to the users of the products that generate PMP's, we may simply introduce a unit tax π_t on all products involved and find the zero-budgeting condition:

$$\pi_t q_t = \frac{w_t^* s_t}{\alpha w_t} \quad (5.5)$$

Next, one may assume a simple demand function with a negative shape with respect to the all-in price p_t , i.e.,

$$\begin{aligned} q_t &= f(p_t) \\ &= f(p_t^* + \pi_t) \end{aligned} \quad (5.6)$$

where p_t^* is the net price without environmental charges.

If in a given situation $z_t > \bar{z}$, the environmental charge π_t may be fixed at such a level that within a given time horizon z_t will equal $\bar{z}$. The tax revenues would have to be transferred as financial inputs to the deposit-refund system. This mechanism is effective on two sides: it stimulates firms to properly treat PMP's (via the bonus system) and it stimulates firms to search for technological solutions (via the demand elasticity on the basis of pollution charges to the users of products). The time period within which one wants to arrive at such a sustainable state may be dependent on cost considerations, requiring essentially a multi-period optimization model.

Such a model would incorporate the conflicts between short-term economic efficiency and long-term sustainability. Hence two objective functions seem to be plausible here:

$$\min \phi_1 = \sum_{t=0}^T z_t \quad (5.7)$$

and

$$\max \phi_2 = \sum_{t=0}^T B_t e^{-rt} \quad (5.8)$$

For the moment, the sustainability objective (5.7) does not have a discount rate, which is a plausible assumption in case of lack of information on future impacts of PMP's.

Instead of objective function (5.7) one might also use a quadratic penalty function, i.e.

$$\min \phi_1^* = \sum_{t=0}^T (z_t - \bar{z})^2 \quad (5.9)$$

We have now essentially a bi-objective optimization model, which may be solved by means of discrete control theory. The control parameters may in this case be the amount of PMP's properly disposed (i.e., w_t^*) and the unit bonus (i.e., s_t).

6. Future Directions

The previous observations have made clear that care of the biosphere cannot be entrusted to a hidden hand. As pointed out above, human interventions in the area of land use, technology and resource extraction are often a threat to ecologically sustainable economic development. The threats of PMP's are a sad illustration of this situation. Strategic economic and environmental policy is essentially also a risk strategy which serves to minimize the mismatch between economic development and ecological sustainability under uncertain future conditions incorporating the dangers of hazardous materials. It seems to be a reasonable strategy to maintain the long-run value of the stock of 'environmental capital', whilst also ensuring sufficient diversity. It is noteworthy that economic well-being in the long run is dependent on the quality of the biosphere. Thus in the long run, the environment should be an ally of the economy. This convergence of interests, called a **co-evolutionary development** (Norgaard, 1984), is likely to exist in various sectors of environmental management and land use.

The fact that conventional economic inputs and environmental capital both may contribute to welfare and may involve a trade-off could imply the need to impose minimum achievement levels (or threshold levels) for both economic and environmental conditions, in order to survive. Thus planning for co-evolutionary development has to be pursued with careful consideration of threshold levels for both the economic and environmental systems.

In this context, the long reaction times of economic and ecological processes often conceal the inexorable links between past and future events as evident in such phenomena as deforestation, ozonization and desertification (Crutzen and Graedel, 1986). Consequently, assuming that sustainability strategies are essentially the result of risk aversion strategies, there is a need to focus on the long-term evolution of economic-ecological systems. A basic problem here is a lack of insight into broad-scale environmental changes taking place over a period of time that do not synchronize with the response time needed to implement effective environmental strategies.

In the light of uncertainties surrounding sustainability strategies, more specific information to make balanced economic-environmental decisions is needed. Such information might not take the form of quantitative data, but rather a set of guiding principles. Strategic and preventive strategies regarding PMP control would require a special focus on the following guiding principles (see James et al., 1989):

- identification of the **crucial ecological processes, ecosystems and resource regenerative systems** which form the infrastructure of the 'natural capital' from which welfare is to be derived in future, and of an appropriate set of indicators to monitor quantitative and qualitative changes in these processes and systems (e.g., environmental indicators on regulatory, carrier, production and information functions of the environmental capital; resource accounting);
- identification of **long-run driving forces** which are most critical to sustainability and which impact on both the economy and the biosphere (e.g., demographic transitions, technological developments, socio-cultural changes) and which will have a supra-marginal influence on the future welfare of society through sometimes complex economic-environmental interactions;
- identification of conditions under which **perturbations** (shocks, discontinuities, surprises etc.) may come about; imaginative thinking, creative environmental entrepreneurship and expert knowledge are necessary conditions for **becoming aware** - on time - of hardly foreseeable events. Surprise management is perhaps the key issue in environmental sustainability policies, as this is based on anticipatory attitudes that induce preventive actions or rapid adjustments;

- identification of **irreversible evolutionary processes**. The aggregate result of numerous small-scale environmental transformations may be devastating to environmental quality conditions in the long run, as there is no scope for reversibility in the foreseeable future;
- Clearly, in view of the great many uncertainties involved in PMP policies, there is a need for serious efforts in the area of environmental **monitoring**, environmental **auditing** and environmental **resource accounting**.

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